Manual Materials Handling Capabilities in Non-standard Postures

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Abstract

Research efforts to establish manual materials handling capabilities of individuals and populations have been conducted for many years at Texas Tech University. Recognizing that all industrial materials handling activities are not two handed symmetric sagittal plane activities, recent research projects have explored materials handling capacities in non-standard postures. Among the non-standard postures examined were: twisting while lifting or lowering, lifting and lowering from lying, sitting, kneeling, and squatting positions, and carrying loads under conditions of constricted ceiling heights. Capacity data are presented for both males and females. In addition to means and standard deviations of the data, percentile distributions for the subject populations are also presented. Sample sizes for the experimental populations range from 20 to 50 subjects of each sex.

1. Introduction

Traditional studies relating to individual and population capacities of manual materials handling activities have studied two-handed, symmetric, sagittal tasks using a rigid container with two handles. Many such studies were summarized and incorporated into the *Work Practices Guide for Manual Lifting* (NIOSH, 1981). However, many industrial activities involve non-symmetric, non-sagittal plane, one handed lifting in postures other than the traditional standing posture. Restrictions in ceiling height may limit postures to stooping, squatting, kneeling, sitting or lying while performing materials handling activities.

Research efforts at Texas Tech have addressed manual materials handling activities in unusual postures for several years (Ayoub, et. al., 1985a, 1985b, 1987, 1988). Models to predict individual capacities from strength tests have been reported, but the actual population capacity data from the experiments has not been reported in the literature. This report will present descriptive statistics of manual materials handling capacities for 99 non-standard tasks.

2. Methods

Four sets of experiments were conducted to establish capacity data. All subjects in the experiments were college students between the ages of 18 and 30 years old. Since much of the research was done to simulate a U.S. Air Force population, only a younger population was studied. Care must be exercised in extrapolating the data to older populations.

Subjects were selected as much as possible to represent a cross section of the U.S. Adult population in terms of height and weight. Table 1 illustrates the subject height/weight distribution for a sample of 50 subjects (Ayoub and Halcomb, 1976). Each cell of the matrix in Table 1 and Table 2 contains the desired number of subjects fitting within the height-weight boundaries of that cell. For other than 50 subjects, the cells are modified linearly.

All subjects underwent an examination by a physician to ensure their fitness for participation in the study. The subjects then went through a familiarization program to acquaint them with the procedures and the equipment utilized during the experiments. The subjects were all college age students, but were inexperienced in terms of extensive manual materials handling backgrounds. The subjects were representative of personnel entering the U. S. military service in terms of age, physical size and weight, and experience.

The data were analyzed and the means and standard deviations and percentile distributions of the subjects' capacities were determined for each task. The 10th, 25th, 50th, 75th, and 90th percentiles of each data set are reported. The percentile data represent actual data points and consequently the 50th percentile data are often slightly different from the mean of the data. The capacity data are presented for all 99 tasks studied.

Table 1. Height-Weight Stratified Sample Plan for Males

Weight (Kg)	1.64	1.72	1.76	1.79	1.83	1.93
102.7	0	1	1	3	5	
84.8	1	2	2	2	3	
79.8	1	2	4	2	1	
75.4	3	2	2	2	1	
70.8	5	3	1	1	0	
56.6						

Height (m)

Table 2. Height-Weight Stratified Sample Plan for Females

Weight (Kg)	1.48	1.57	1.60	1.64	1.67	1.78
81.9	0	1	1	3	5	
63.6	1	2	2	2	3	
59.0	1	2	4	2	1	
55.4	3	2	2	2	1	
51.3	5	3	1	1	0	
42.3						

Height (m)

3. Results

Experiment 1.

For Experiment 1, 100 subjects were recruited to participate in the experiment, and 93 completed the experiment (45 males and 48 females). The controlled factors in Experiment 1 were: frequency of lift (6 lifts per minute), box size (.3m x .45m x .3m), container (cardboard box without handles) and environmental conditions (approximately 24°C, 50% relative humidity). No specific method of lifting was suggested for the tasks and the subjects were allowed to develop their own "free-style" method of lifting. The manual materials handling tasks were performed in random order.

Experiment 1 was run to determine manual materials handling capacities for handling cardboard boxes without handles. The activity involved lifting, lowering and transferring a box from one level to another. The experiment was a psychophysical experiment in which the subject adjusted the weight in the box until he or she reached the psychophysical maximum acceptable weight of lift for the task conditions. Weight adjustment was accomplished by adding or subtracting odd size, unmarked lead weights. After the subject determined the maximum acceptable weight to be handled for the given task, he or she continued to lift that weight for at least 20 minutes. During the work period, the subject's heart rate was monitored to insure that the subject was working at an acceptable physiological level. The box was weighed after the subject left the test area. No performance data were given to the subject.

The tasks studied in Experiment 1 included:

1. **Lift Knuckle to Shoulder and Twist-** The subject was positioned between two shelves located 0.76 and 1.27m above the floor and approximately 1.5m apart. The subject twisted to the left and lifted the box off the shelf, twisted to the right and placed the box on the higher shelf.

2. **Lift Knuckle to Shoulder and Carry-** The subject faced the shorter shelf, lifted the box, turned around (180°) took a step and lifted the box to the higher shelf.

3. **Lower Shoulder to Knuckle and Twist-** Reverse of #1.

4. **Lower Shoulder to Knuckle and Carry-** Reverse of #2.

5. **Lift Floor to Shoulder and Twist-** The subject was positioned between the box on the floor and a shelf located 1.27m above the floor. The subject twisted to the left, bent down and lifted the box off the floor, twisted to the right and placed the box on the shelf.

6. **Lift Floor to Shoulder and Carry-** The subject bent down, lifted the box, stood up, turned (180°), took a step and lifted the box onto the shelf.

7. **Lower Shoulder to Floor and Twist-** Reverse of #5.

8. **Lower Shoulder to Floor and Carry-** Reverse of #6.

9. **Lower Knuckle to Floor and Twist-** The subject twisted to the right, lifted the box of the shelf, twisted to the left, bent down and placed the box on the floor.

10. Lower Knuckle to Floor and Carry- The subject faced the shelf, lifted the box, turned (180°), took a step, bent down and placed the box on the floor.

11. Lift Kneeling on 2 Knees Floor to 0.6m- The subject was positioned on both knees between the box and the shelf. The subject twisted to the left, picked up the box, twisted to the right and lifted the box onto the shelf.

12. Lift Kneeling on 1 Knee Floor to 0.6m- The subject was positioned in a kneeling posture (left knee on the floor) between the box and the shelf. The subject twisted to the left, picked up the box, twisted to the right and lifted the box onto the shelf.

13. Horizontal Transfer Kneeling on 2 Knees- Subject knelt on both knees, twisted to the left, picked the box up from the floor, twisted to the right and lowered the box back onto the floor.

14. Horizontal Transfer Seated- The subjects sat on the floor with legs extended straight in front of him or her, twisted to the left, picked the box up off the floor, twisted to the right and placed the box back onto the floor.

15. Lower Kneeling on 2 Knees 0.6m to Floor- Reverse of #11.

The capacity data and population percentiles for Experiment 1 are presented in Tables 3 and 4. Table 3 shows the capacity data for female subjects, while Table 4 shows the capacity data for the male subjects.

Table 3. MMH Capacity Data (kg) for Female Subjects in Experiment 1. (Frequency = 6 lifts/minute)

MMH Activity	Mean	SD	Percentile Distribution of Data 10	25	50	75	90
Lift Knuckle to Shoulder and Twist	9.1	2.2	6.2	7.7	9.2	10.3	12.0
Lift Knuckle to Shoulder and Carry	9.3	2.3	6.9	7.9	9.0	10.4	12.4
Lower Shoulder to Knuckle and Twist	9.5	2.7	6.5	7.7	9.4	10.9	12.2
Lower Shoulder to Knuckle and Carry	9.3	2.2	6.7	7.7	9.2	11.1	12.4
Lift Floor to Shoulder and Twist	8.2	2.2	6.4	6.9	7.7	9.0	11.0
Lift Floor to Shoulder and Carry	8.3	2.0	5.8	6.9	8.0	9.5	11.0
Lower Shoulder to Floor and Twist	9.4	2.1	7.0	7.7	9.3	10.8	11.8
Lower Shoulder to Floor and Carry	9.8	2.2	7.3	8.2	9.5	10.7	13.2
Lower Knuckle to Floor and Twist	9.9	2.4	7.0	8.4	9.8	11.0	12.5
Lower Knuckle to Floor and Carry	11.3	3.1	7.8	9.1	10.8	12.8	16.4
Lift Kneeling on 2 Knees Floor to 0.61 m	9.3	2.3	6.8	7.7	8.8	10.7	11.9
Lift Kneeling on 1 Knee Floor to 0.61 m	8.8	1.8	6.8	7.6	8.6	9.5	11.4
Horizontal Transfer Kneeling on 2 Knees	9.4	1.7	7.3	8.0	9.3	10.6	11.7
Horizontal Transfer Seated	8.3	2.0	6.5	7.4	8.4	9.4	10.4
Lower Kneeling on 2 Knees 0.61 m to Flr	10.3	2.2	7.5	8.6	10.2	11.3	12.7

Table 4. MMH Capacity Data (kg) for Male Subjects in Experiment 1. (Frequency = 6 lifts/minute)

MMH Activity	Mean	SD	Percentile Distribution of Data 10	25	50	75	90
Lift Knuckle to Shoulder and Twist	18.6	5.9	12.6	14.4	17.6	21.8	26.5
Lift Knuckle to Shoulder and Carry	18.8	6.0	12.2	14.9	17.2	21.8	27.4
Lower Shoulder to Knuckle and Twist	18.9	5.8	12.5	14.5	18.1	21.2	26.1
Lower Shoulder to Knuckle and Carry	21.0	7.5	13.2	15.2	19.7	25.4	28.8
Lift Floor to Shoulder and Twist	15.6	4.1	10.9	12.6	15.0	17.6	22.7
Lift Floor to Shoulder and Carry	15.6	4.1	10.4	12.5	14.7	18.4	21.3
Lower Shoulder to Floor and Twist	17.5	4.8	11.6	13.7	17.0	20.3	23.4
Lower Shoulder to Floor and Carry	19.2	5.9	12.9	15.6	17.9	22.6	26.3
Lower Knuckle to Floor and Twist	19.4	5.3	12.7	16.2	17.9	21.3	26.1
Lower Knuckle to Floor and Carry	19.9	5.8	12.9	16.0	19.3	24.1	28.1
Lift Kneeling on 2 Knees Floor to 0.61 m	17.6	4.5	11.2	15.2	17.4	20.4	22.9
Lift Kneeling on 1 Knee Floor to 0.61 m	16.7	4.4	10.8	12.5	17.4	20.0	22.7
Horizontal Transfer Kneeling on 2 Knees	18.4	4.9	12.2	14.3	17.9	22.7	25.4
Horizontal Transfer Seated	14.6	3.5	10.1	11.6	14.5	17.5	19.7
Lower Kneeling on 2 Knees 0.61 m to Flr	21.5	6.0	13.5	16.3	21.8	26.1	28.1

Experiment 2.

Experiment 2 examined manual materials handling tasks that might be encountered in maintenance activities. One hundred Texas Tech students (50 males and 50 females) were recruited to participate in the study and all 100 subjects completed the experiment. The subjects were selected to be representative of the U.S. adult population and were selected according to the height-weight criteria of Tables 1 and 2. The same set of subjects used in Experiment 1 was used for Experiment 2, with the addition of 5 males and 2 females to bring the total subject size to 100.

A psychophysical methodology was utilized in Experiment 2 to determine the subject's one time maximum acceptable weight of lift for the various task conditions. Weight adjustment was accomplished by adding or subtracting odd sized, unmarked lead weights. The subject was under no time constraints and could make as many adjustments as necessary to arrive at his or her maximum acceptable weight of lift for a one time lift. The box was weighed after the subject left the test area, and no performance feedback was provided to the subject.

The tasks studied in Experiment 2 included:

1. Lying Face Down, Lift with One Hand- The subject was instructed to lay prone on a 1.2m high platform and extend his or her arm through a 35 x 35cm opening in the platform. With the arm fully extended, the subject grasped the handle of a 25 x 25cm box (30 cm high) and lifted it through the opening and placed it on the platform. The subject was allowed to prop up his or her body using the forearms. The task was repeated for both the left and right arm.

Table 5. MMH Capacity Data (kg) for Female Subjects in Experiment 2.

MMH Activity	Mean	SD	Percentile Distribution of Data 10	25	50	75	90
Lying Face Down, Lift with Left Hand	9.1	2.0	6.8	7.5	8.8	10.4	11.9
Lying Face Down, Lift with Right Hand	9.3	1.8	7.2	7.5	8.6	10.4	12.0
1 Hand Lying Side Lift Close	6.5	1.4	4.8	5.4	6.6	7.5	8.3
1 Hand Lying Side Lift Far	6.7	1.4	4.5	5.7	6.8	7.7	8.5
2 Hand Lying Side Lift Close	8.1	1.9	5.2	6.6	8.2	9.8	10.8
2 Hand Lying Side Lift Far	8.9	2.1	6.1	7.5	9.1	10.7	11.3
1 Hand Lying Face Up Lift Close	9.5	2.4	6.6	7.5	9.2	11.1	13.0
1 Hand Lying Face Up Lift Far	13.0	3.3	8.6	10.4	12.8	15.2	17.7
2 Hand Lying Face Up Lift Close	24.3	4.7	19.1	20.9	23.8	26.8	30.8
2 Hand Lying Face Up Lift Far	29.5	5.2	23.4	26.1	28.8	32.2	35.4
1 Hand Toolbox Lift Floor to 0.76 m	20.2	3.8	16.1	17.5	19.4	21.5	26.0

Table 6. MMH Capacity Data (kg) for Male Subjects in Experiment 2.

MMH Activity	Mean	SD	Percentile Distribution of Data 10	25	50	75	90
Lying Face Down, Lift with Left Hand	19.2	4.5	14.1	15.4	18.4	22.6	24.5
Lying Face Down, Lift with Right Hand	19.4	4.8	14.3	15.5	19.0	22.0	25.5
1 Hand Lying Side Lift Close	13.6	3.0	10.0	11.8	12.9	15.4	17.7
1 Hand Lying Side Lift Far	13.3	2.6	10.0	11.2	13.2	14.7	15.9
2 Hand Lying Side Lift Close	15.7	3.5	11.8	12.9	15.5	17.9	21.8
2 Hand Lying Side Lift Far	17.9	3.8	13.1	15.5	17.4	19.7	23.6
1 Hand Lying Face Up Lift Close	19.9	5.8	13.4	16.3	19.3	22.0	28.5
1 Hand Lying Face Up Lift Far	24.9	6.1	17.9	19.5	25.0	28.6	34.2
2 Hand Lying Face Up Lift Close	55.6	13.8	39.4	45.6	53.6	63.1	77.4
2 Hand Lying Face Up Lift Far	66.9	15.9	47.4	53.1	62.6	78.9	90.8
1 Hand Toolbox Lift Floor to 0.76 m	44.0	8.0	34.1	37.2	44.0	49.2	54.2

Experiment 3.

Experiment 3 also examined manual materials handling tasks that might be encountered in maintenance activities. One hundred Texas Tech students (50 males and 50 females) were recruited to participate in the study and all 100 subjects completed the experiment. The subjects were selected to be representative of the U.S. adult population and were selected according to the height-weight criteria of Tables 1 and 2. The subjects in Experiment 3 were not the same subjects that participated in Experiments 1 or 2.

The tasks in Experiment 3 were divided into three general categories of tasks: two-handed lifting tasks, one-handed lifting tasks, and side lifts. For the one and two-handed lifting tasks, the subjects assumed the following postures: standing, sitting on a 51cm surface, squatting, kneeling on the left knee, and kneeling on both knees. For the two-handed lifting tasks the subjects lifted a box measuring 61 x 30 x 15cm. The box was lifted in all three orientations to determine the effect of box shape on lifting capacity. For the one-hand lifts, the subjects used their right hand to lift a container measuring 25 x 25 x 28cm by grasping a handle located 25cm from the bottom of the container.

For both the one and two-handed lifting tasks, subjects lifted the box to 35, 60, and 85% of their vertical reach for each of the five lifting postures. For the one-handed lifting tasks, 25cm was subtracted from the calculated task placement height to compensate for the fact that the handle on the container was located 25cm from the bottom of the container. When placing the box on the shelf, the subject was required to do so with precision. Guides were placed on the shelf to allow for approximately 1cm clearance on each side of the box, when it was placed on the shelf. The subject was instructed not to touch the guides with the box when placing the box on the shelf. The precision component was introduced to simulate maintenance activities in which objects must be lifted into a precise location (such as removal and replacement of equipment components).

For the side lifts, the subjects lay on their left side with their body parallel to and at functional reach from a 25cm high platform. For the one-hand lift, subjects lifted a 36 x 20 x 12cm container with a handle running the 36cm length of the container, located 10cm above the bottom of the container. For the two-handed lift, subjects lifted a 20 x 20 x 22cm container with no handle. In all cases, the subjects lifted the container from the floor and placed it on the 25cm high platform. Two postures were employed. For one posture the subjects had their upper legs curled so that their lower legs bent back at a 90° angle. The second posture was the same for the lower (left) leg, but allowed the upper (right) leg to be brought forward to be used as a brace. Two box location positions were used: as close to the body as possible, and at elbow distance from the body.

A psychophysical methodology was utilized in Experiment 3 to determine the subject's one time maximum acceptable weight of lift for the various task conditions. Weight adjustment was accomplished by adding or subtracting odd sized, unmarked lead weights. The subject was under no time constraints and could make as many adjustments as necessary to arrive at his or her maximum acceptable weight of lift for a one time lift. The box was weighed after the subject left the test area, and no performance feedback was provided to the subject.

The various posture, container size and orientation, and the height of lift combinations resulted in a total of 68 tasks for Experiment 3. Several work stations were set up to allow the tasks to be run in random order for the subjects.

The two-handed lifting tasks studied in Experiment 3a included:

1. Standing Lifts- The subject bent down, picked the box up off the floor, lifted the box and placed it on a shelf that was adjusted in height to 35, 60, and 85% of the subject's standing vertical reach. The subject was required to precisely place the box on the shelf without touching the clearance guides. The lift was repeated for each of three box orientations.

2. Sitting Lifts- The subject was instructed to sit on a 30cm high surface. The subject bent over, picked the box up off the floor, lifted the box and placed it on a shelf that was adjusted in height to 35, 60, and 85% of the subject's sitting vertical reach. The subject was required to precisely place the box on the shelf without touching the clearance guides. The lift was repeated for each of three box orientations.

3. Squatting Lifts- The subject was instructed to assume as comfortable a squat posture as possible. The subject bent over, picked the box up off the floor, lifted the box and placed it on a shelf that was adjusted in height to 35, 60, and 85% of the subject's squatting vertical reach. The subject was required to precisely place the box on the shelf without touching the clearance guides. The lift was repeated for each of three box orientations.

4. Kneeling 1 Knee Lifts- The subject was instructed to kneel with the left knee on the floor and the right knee up. The subject bent over, picked the box up off the floor, lifted the box and placed it on a shelf that was adjusted in height to 35, 60, and 85% of the subject's kneeling vertical reach. The subject was required to precisely place the box on the shelf without touching the clearance guides. The lift was repeated for each of three box orientations.

5. Kneeling 2 Knee Lifts- The subject was instructed to kneel with the both knees on the floor. The subject bent over, picked the box up off the floor, lifted the box and placed it on a shelf that was adjusted in height to 35, 60, and 85% of the subject's kneeling vertical reach. The subject was required to precisely place the box on the shelf without touching the clearance guides. The lift was repeated for each of three box orientations.

The capacity data and population percentiles for Experiment 3a are presented in Tables 7 and 8. Table 7 shows the capacity data for female subjects, while Table 8 shows the capacity data for the male subjects. Because the box used in Experiment 3 was utilized in all three orientations, the box had a lid that could be closed and locked shut so that weights would not fall out during the lift. In order to maintain stability of the center of mass, weighted rods were used to add or subtract weight from the box. The rods had masses of 2.25kg each, but were not marked with their mass. Therefore, the capacity data obtained from Experiment 3 was in increments of 2.25kg, and many of the subject's capacities were the same mass. This can be found in Tables 7 and 8 when two adjacent percentiles are the same value. If 8 or 10 observations of capacity data were the same value, it is very likely that two adjacent percentiles of the capacity data would be the same.

Table 7 Two-Hand Lifting Capacity Data (kg) for Female Subjects in Experiment 3a.

MMH Activity	Mean	SD	Percentile Distribution of Data 10	25	50	75	90
Flat Container (61.0 x 30.5 x 15.2 cm)							
Standing Lift Floor to 35% Standing Fn Rch	26.4	6.1	20.4	20.4	24.9	29.5	34.0
Standing Lift Floor to 60% Standing Fn Rch	21.2	3.5	15.9	18.1	20.4	24.9	24.9
Standing Lift Floor to 85% Standing Fn Rch	16.7	2.9	13.6	13.6	15.9	18.1	20.4
Sitting Lift Floor to 35% Sitting Fn Rch	22.3	4.3	18.1	20.4	20.4	24.9	27.2
Sitting Lift Floor to 60% Sitting Fn Rch	17.9	3.0	13.6	15.9	18.1	20.4	22.7
Sitting Lift Floor to 85% Sitting Fn Rch	14.5	2.6	11.0	13.6	13.6	15.9	18.1
Squatting Lift Floor to 35% Squat Fn Rch	19.4	2.8	15.9	18.1	20.4	20.4	22.7
Squatting Lift Floor to 60% Squat Fn Rch	16.0	2.7	12.9	13.6	15.9	18.1	20.4
Squatting Lift Floor to 85% Squat Fn Rch	13.0	2.9	9.3	11.8	13.6	15.9	15.9
Kneeling 1 Knee Lift Floor to 35% K Fn Rch	24.0	4.4	18.1	20.4	24.9	27.2	29.5
Kneeling 1 Knee Lift Floor to 60% K Fn Rch	18.9	3.1	15.9	15.9	18.1	20.4	22.7
Kneeling 1 Knee Lift Floor to 85% K Fn Rch	15.3	2.8	11.3	13.6	15.9	18.1	18.1
Kneeling 2 Knee Lift Floor to 35% K Fn Rch	24.3	5.5	18.1	20.4	22.7	27.2	34.0
Kneeling 2 Knee Lift Floor to 60% K Fn Rch	18.2	3.2	13.6	15.9	18.1	20.4	22.7
Kneeling 2 Knee Lift Floor to 85% K Fn Rch	15.2	2.7	12.2	13.6	15.9	18.1	18.1
Vertical Container (30.5 x 15.2 x 61.0 cm)							
Standing Lift Floor to 35% Standing Fn Rch	26.0	5.2	19.2	22.7	24.9	29.5	31.8
Standing Lift Floor to 60% Standing Fn Rch	18.9	2.7	15.9	15.9	18.1	20.4	22.7
Standing Lift Floor to 85% Standing Fn Rch	14.5	2.2	11.6	13.6	13.6	15.9	18.1
Sitting Lift Floor to 35% Sitting Fn Rch	21.3	4.0	18.1	18.1	20.4	22.7	28.1
Sitting Lift Floor to 60% Sitting Fn Rch	16.6	2.5	13.6	13.6	15.9	18.1	20.4
Sitting Lift Floor to 85% Sitting Fn Rch	12.4	2.3	9.5	10.9	12.4	13.6	14.8
Squatting Lift Floor to 35% Squat Fn Rch	18.4	3.1	15.9	15.9	18.1	20.4	22.7
Squatting Lift Floor to 60% Squat Fn Rch	15.1	2.2	13.6	13.6	14.8	15.9	18.1
Squatting Lift Floor to 85% Squat Fn Rch	11.5	2.7	8.7	9.3	11.6	13.6	14.8
Kneeling 1 Knee Lift Floor to 35% K Fn Rch	21.6	3.4	18.1	20.4	20.4	22.7	27.2
Kneeling 1 Knee Lift Floor to 60% K Fn Rch	17.1	2.2	13.6	15.9	18.1	18.1	20.4
Kneeling 1 Knee Lift Floor to 85% K Fn Rch	13.4	1.9	11.0	12.0	13.6	13.6	15.9
Kneeling 2 Knee Lift Floor to 35% K Fn Rch	21.4	4.1	15.9	18.1	21.6	24.9	27.2
Kneeling 2 Knee Lift Floor to 60% K Fn Rch	16.6	2.3	13.6	15.9	15.9	18.1	20.4
Kneeling 2 Knee Lift Floor to 85% K Fn Rch	12.9	1.7	10.2	12.2	13.6	13.6	13.6
Deep Container (15.2 x 61.0 x 30.4 cm)							
Standing Lift Floor to 35% Standing Fn Rch	25.4	4.5	20.4	22.7	24.9	27.2	31.8
Standing Lift Floor to 60% Standing Fn Rch	20.8	3.1	15.9	18.1	20.4	22.7	24.9
Standing Lift Floor to 85% Standing Fn Rch	16.7	2.3	13.6	15.9	15.9	18.1	20.4
Sitting Lift Floor to 35% Sitting Fn Rch	21.2	3.9	18.1	18.1	20.4	22.7	24.9
Sitting Lift Floor to 60% Sitting Fn Rch	17.6	2.8	13.6	15.9	18.1	18.1	20.4
Sitting Lift Floor to 85% Sitting Fn Rch	14.1	2.3	11.3	13.6	13.6	15.9	15.9
Squatting Lift Floor to 35% Squat Fn Rch	20.1	3.7	15.9	18.1	20.4	22.7	24.9
Squatting Lift Floor to 60% Squat Fn Rch	17.0	2.8	13.6	15.9	15.9	18.1	20.4
Squatting Lift Floor to 85% Squat Fn Rch	13.6	2.2	10.9	12.7	13.6	15.9	15.9
Kneeling 1 Knee Lift Floor to 35% K Fn Rch	23.6	4.5	18.1	20.4	22.7	27.2	29.5
Kneeling 1 Knee Lift Floor to 60% K Fn Rch	19.1	2.9	15.9	18.1	18.1	20.4	22.7
Kneeling 1 Knee Lift Floor to 85% K Fn Rch	15.8	1.9	13.6	13.6	15.9	15.9	18.1
Kneeling 2 Knee Lift Floor to 35% K Fn Rch	23.9	3.8	18.1	20.4	24.9	24.9	29.5
Kneeling 2 Knee Lift Floor to 60% K Fn Rch	19.3	2.5	15.9	18.1	18.1	20.4	22.7
Kneeling 2 Knee Lift Floor to 85% K Fn Rch	16.0	2.4	13.6	13.6	15.9	18.1	19.2

Table 8. Two-Hand Lifting Capacity Data (kg) for Male Subjects in Experiment 3a.

MMH Activity	Mean	SD	Percentile Distribution of Data 10	25	50	75	90
Flat Container (61.0 x 30.5 x 15.2 cm)							
Standing Lift Floor to 35% Standing Fn Rch	53.5	10.6	39.7	43.1	54.4	61.2	70.3
Standing Lift Floor to 60% Standing Fn Rch	40.8	7.2	31.8	34.0	40.8	45.4	51.0
Standing Lift Floor to 85% Standing Fn Rch	32.9	6.2	27.2	29.5	34.0	36.3	38.6
Sitting Lift Floor to 35% Sitting Fn Rch	41.6	8.4	32.9	36.3	40.8	45.4	47.6
Sitting Lift Floor to 60% Sitting Fn Rch	33.8	5.5	28.4	29.5	31.8	36.3	43.1
Sitting Lift Floor to 85% Sitting Fn Rch	28.4	5.8	20.4	24.9	28.4	31.8	36.3
Squatting Lift Floor to 35% Squat Fn Rch	35.8	6.3	29.5	31.8	34.0	38.6	45.4
Squatting Lift Floor to 60% Squat Fn Rch	29.4	5.0	22.7	27.2	29.5	31.8	37.4
Squatting Lift Floor to 85% Squat Fn Rch	24.3	5.0	18.1	22.7	24.9	27.2	29.5
Kneeling 1 Knee Lift Floor to 35% K Fn Rch	44.9	9.3	34.0	38.6	45.4	49.9	57.8
Kneeling 1 Knee Lift Floor to 60% K Fn Rch	34.8	6.2	27.2	31.8	34.0	38.6	42.0
Kneeling 1 Knee Lift Floor to 85% K Fn Rch	30.4	5.6	23.8	27.2	31.8	34.0	36.3
Kneeling 2 Knee Lift Floor to 35% K Fn Rch	42.9	9.0	34.0	36.3	40.8	47.6	56.7
Kneeling 2 Knee Lift Floor to 60% K Fn Rch	35.3	5.9	27.2	31.8	35.2	38.6	42.0
Kneeling 2 Knee Lift Floor to 85% K Fn Rch	30.0	5.6	22.7	27.2	29.5	31.8	36.3
Vertical Container (30.5 x 15.2 x 61.0 cm)							
Standing Lift Floor to 35% Standing Fn Rch	54.7	9.7	42.0	47.6	54.4	61.2	70.3
Standing Lift Floor to 60% Standing Fn Rch	36.6	7.4	28.4	31.8	36.3	38.6	45.4
Standing Lift Floor to 85% Standing Fn Rch	29.3	6.0	22.7	24.9	29.5	34.0	38.6
Sitting Lift Floor to 35% Sitting Fn Rch	39.9	8.1	31.8	34.0	37.4	43.1	52.2
Sitting Lift Floor to 60% Sitting Fn Rch	33.0	6.7	27.2	29.5	31.8	36.3	43.1
Sitting Lift Floor to 85% Sitting Fn Rch	23.2	4.6	18.1	20.4	22.7	24.9	28.4
Squatting Lift Floor to 35% Squat Fn Rch	34.3	6.0	27.2	29.5	34.0	38.6	42.0
Squatting Lift Floor to 60% Squat Fn Rch	28.4	5.4	22.7	24.9	27.2	31.8	36.3
Squatting Lift Floor to 85% Squat Fn Rch	21.5	5.2	17.0	18.1	20.4	22.7	28.4
Kneeling 1 Knee Lift Floor to 35% K Fn Rch	41.4	8.6	32.9	36.3	40.8	45.4	53.3
Kneeling 1 Knee Lift Floor to 60% K Fn Rch	33.6	6.0	27.2	29.5	32.9	36.3	43.1
Kneeling 1 Knee Lift Floor to 85% K Fn Rch	25.2	4.4	20.4	22.7	24.9	27.2	31.8
Kneeling 2 Knee Lift Floor to 35% K Fn Rch	40.8	7.2	34.0	36.3	39.7	47.6	49.9
Kneeling 2 Knee Lift Floor to 60% K Fn Rch	33.4	5.8	28.4	29.5	31.8	36.3	40.8
Kneeling 2 Knee Lift Floor to 85% K Fn Rch	25.1	4.5	19.2	22.7	24.9	27.2	31.8
Deep Container (15.2 x 61.0 x 30.4 cm)							
Standing Lift Floor to 35% Standing Fn Rch	54.0	10.7	42.0	45.4	49.9	65.8	70.3
Standing Lift Floor to 60% Standing Fn Rch	41.8	6.7	34.0	36.3	40.8	45.4	49.9
Standing Lift Floor to 85% Standing Fn Rch	34.8	6.8	27.2	29.5	34.0	38.6	45.4
Sitting Lift Floor to 35% Sitting Fn Rch	39.7	6.9	31.8	34.0	38.6	43.1	49.9
Sitting Lift Floor to 60% Sitting Fn Rch	32.5	5.1	27.2	29.5	31.8	36.3	39.7
Sitting Lift Floor to 85% Sitting Fn Rch	27.3	5.0	22.7	22.7	27.2	29.5	34.0
Squatting Lift Floor to 35% Squat Fn Rch	38.3	6.7	30.6	34.0	38.6	43.1	46.5
Squatting Lift Floor to 60% Squat Fn Rch	32.0	5.1	26.0	27.2	31.8	36.3	38.6
Squatting Lift Floor to 85% Squat Fn Rch	25.6	5.0	20.4	22.7	24.9	29.5	31.8
Kneeling 1 Knee Lift Floor to 35% K Fn Rch	46.0	10.2	36.3	38.3	44.3	52.2	59.0
Kneeling 1 Knee Lift Floor to 60% K Fn Rch	36.8	6.9	31.8	31.8	36.3	40.8	45.4
Kneeling 1 Knee Lift Floor to 85% K Fn Rch	30.3	5.1	24.9	27.2	29.5	34.0	36.3
Kneeling 2 Knee Lift Floor to 35% K Fn Rch	46.7	9.4	35.2	38.6	45.4	52.2	60.1
Kneeling 2 Knee Lift Floor to 60% K Fn Rch	36.6	7.8	29.5	31.8	36.3	40.8	45.4
Kneeling 2 Knee Lift Floor to 85% K Fn Rch	30.2	5.6	22.7	27.2	29.5	34.0	36.3

The one-handed lifting tasks studied in Experiment 3b included:

1. Standing Lifts- The subject bent down, grasped the handle of the box with one hand, picked the box up off the floor, lifted the box and placed it on a shelf that was adjusted in height to 35, 60, and 85% of the subject's standing vertical reach. The subject was required to precisely place the box on the shelf without touching the clearance guides. The lift was repeated for each of three box orientations.

2. Sitting Lifts- The subject was instructed to sit on a 30cm high surface. The subject bent over, grasped the handle of the box with one hand, picked the box up off the floor, lifted the box and placed it on a shelf that was adjusted in height to 35, 60, and 85% of the subject's sitting vertical reach. The subject was required to precisely place the box on the shelf without touching the clearance guides. The lift was repeated for each of three box orientations.

3. Squatting Lifts- The subject was instructed to assume as comfortable a squat posture as possible. The subject bent over, grasped the handle of the box with one hand, picked the box up off the floor, lifted the box and placed it on a shelf that was adjusted in height to 35, 60, and 85% of the subject's squatting vertical reach. The subject was required to precisely place the box on the shelf without touching the clearance guides. The lift was repeated for each of three box orientations.

4. Kneeling 1 Knee Lifts- The subject was instructed to kneel with the left knee on the floor and the right knee up. The subject bent over, grasped the handle of the box with one hand, picked the box up off the floor, lifted the box and placed it on a shelf that was adjusted in height to 35, 60, and 85% of the subject's kneeling vertical reach. The subject was required to precisely place the box on the shelf without touching the clearance guides. The lift was repeated for each of three box orientations.

5. Kneeling 2 Knee Lifts- The subject was instructed to kneel with the both knees on the floor. The subject bent over, grasped the handle of the box with one hand, picked the box up off the floor, lifted the box and placed it on a shelf that was adjusted in height to 35, 60, and 85% of the subject's kneeling vertical reach. The subject was required to precisely place the box on the shelf without touching the clearance guides. The lift was repeated for each of three box orientations.

The capacity data and population percentiles for Experiment 3b are presented in Tables 9 and 10. Table 9 shows the capacity data for female subjects, while Table 10 shows the capacity data for the male subjects. For the one-handed lift, adjustment weights were odd unmarked lead weights that could be added or removed from the box to arrive at the subject's maximum acceptable weight of lift for the task.

Table 9. 1 Hand Lifting Capacity Data (kg) for Female Subjects in Experiment 3b.

MMH Activity	Mean	SD	Percentile Distribution of Data 10	25	50	75	90
Standing Lift Floor to 35% Standing Fn Rch	29.8	7.8	20.6	23.1	29.0	35.2	38.7
Standing Lift Floor to 60% Standing Fn Rch	15.2	2.7	11.8	13.2	15.2	16.8	18.5
Standing Lift Floor to 85% Standing Fn Rch	9.3	1.5	7.5	8.2	9.1	10.2	11.4
Sitting Lift Floor to 35% Sitting Fn Rch	15.9	2.5	12.2	14.5	15.9	17.9	18.7
Sitting Lift Floor to 60% Sitting Fn Rch	10.5	2.3	7.9	8.8	10.7	11.8	13.5
Sitting Lift Floor to 85% Sitting Fn Rch	7.5	1.3	6.1	6.8	7.3	8.4	9.4
Squatting Lift Floor to 35% Squat Fn Rch	15.2	3.0	11.4	13.6	15.4	17.0	18.4
Squatting Lift Floor to 60% Squat Fn Rch	10.6	2.2	7.7	9.1	10.9	11.8	12.4
Squatting Lift Floor to 85% Squat Fn Rch	7.5	1.3	6.0	6.8	7.3	8.2	9.3
Kneeling 1 Knee Lift Floor to 35% K Fn Rch	17.5	3.5	13.2	15.0	17.0	19.7	22.4
Kneeling 1 Knee Lift Floor to 60% K Fn Rch	11.8	2.8	8.0	9.5	12.0	13.8	14.8
Kneeling 1 Knee Lift Floor to 85% K Fn Rch	7.9	1.4	6.1	6.8	7.7	8.6	9.8
Kneeling 2 Knee Lift Floor to 35% K Fn Rch	17.8	3.2	14.4	15.0	17.5	20.0	22.8
Kneeling 2 Knee Lift Floor to 60% K Fn Rch	11.9	2.6	8.3	10.4	11.8	13.8	14.8
Kneeling 2 Knee Lift Floor to 85% K Fn Rch	7.9	1.5	6.2	6.8	7.6	8.6	9.8

Table 10. 1 Hand Lifting Capacity Data (kg) for Male Subjects in Experiment 3b.

MMH Activity	Mean	SD	Percentile Distribution of Data 10	25	50	75	90
Standing Lift Floor to 35% Standing Fn Rch	60.2	14.0	43.1	54.2	61.8	71.2	75.0
Standing Lift Floor to 60% Standing Fn Rch	27.2	5.6	21.8	23.6	26.8	29.9	35.7
Standing Lift Floor to 85% Standing Fn Rch	16.7	3.1	12.4	13.6	17.6	18.8	20.6
Sitting Lift Floor to 35% Sitting Fn Rch	30.1	5.3	24.4	25.4	29.8	34.2	36.3
Sitting Lift Floor to 60% Sitting Fn Rch	18.6	3.5	14.8	15.9	18.1	20.9	23.7
Sitting Lift Floor to 85% Sitting Fn Rch	14.7	4.2	11.6	12.7	14.0	15.4	17.4
Squatting Lift Floor to 35% Squat Fn Rch	29.3	6.3	23.0	26.1	28.4	32.2	36.5
Squatting Lift Floor to 60% Squat Fn Rch	18.2	3.8	14.0	15.4	17.7	20.2	23.4
Squatting Lift Floor to 85% Squat Fn Rch	14.0	2.4	11.3	12.2	13.5	15.4	17.9
Kneeling 1 Knee Lift Floor to 35% K Fn Rch	35.7	8.5	26.5	30.8	35.2	41.5	46.7
Kneeling 1 Knee Lift Floor to 60% K Fn Rch	19.6	4.7	14.5	15.9	19.4	23.1	26.0
Kneeling 1 Knee Lift Floor to 85% K Fn Rch	15.3	2.5	12.5	13.4	14.7	17.2	19.2
Kneeling 2 Knee Lift Floor to 35% K Fn Rch	33.0	7.4	25.4	29.5	31.9	37.4	43.7
Kneeling 2 Knee Lift Floor to 60% K Fn Rch	20.3	4.5	15.3	17.0	20.0	23.1	27.7
Kneeling 2 Knee Lift Floor to 85% K Fn Rch	15.1	2.5	12.1	13.4	14.5	15.9	18.8

The side lifting tasks studied in Experiment 3c included:

1. 1 Hand Lying Side Lifts- The subject was instructed to lay on his/her side with the body parallel to a 25cm high platform. The subject then curled up his or her legs until the lower legs formed a 90° angle with the upper legs. The subject then grasped the box by the handle, lifted the box and placed it on the raised platform. The task was repeated for a similar posture, that allowed the subject to bring the top leg forward to act as a brace during the lifting activity. Lifts were performed for two starting positions for the box: as close to the body (shoulder) as possible, and the rear edge of the box at elbow distance from the body.

1. 2 Hand Lying Side Lifts- The subject was instructed to lay on his/her side with the body parallel to a 25cm high platform. The subject then curled up his or her legs until the lower legs formed a 90° angle with the upper legs. The subject then grasped the box with both hands, lifted the box and placed it on the raised platform. The task was repeated for a similar posture, that allowed the subject to bring the top leg forward to act as a brace during the lifting activity. Lifts were performed for two starting positions for the box: as close to the body (shoulder) as possible, and the rear edge of the box at elbow distance from the body.

The capacity data and population percentiles for Experiment 3c are presented in Tables 11 and 12. Table 11 shows the capacity data for female subjects, while Table 12 shows the capacity data for the male subjects. For the side lift, adjustment weights were odd unmarked lead weights that could be added or removed from the box to arrive at the subject's maximum acceptable weight of lift for the task.

Table 11. MMH Capacity Data (kg) for Female Subjects in Experiment 3c.

MMH Activity	Mean	SD	Percentile Distribution of Data 10	25	50	75	90
1 Hand Lying Side Lift Legs @ 90° Close	7.2	1.4	5.1	6.1	7.3	7.9	8.6
1 Hand Lying Side Lift Legs Braced Close	7.4	1.5	5.7	6.1	7.3	8.2	9.3
1 Hand Lying Side Lift Legs @ 90° Far	7.2	1.4	5.3	5.9	7.3	8.4	8.8
1 Hand Lying Side Lift Legs Braced Far	7.2	1.4	5.4	6.4	7.3	8.2	9.2
2 Hand Lying Side Lift Legs @ 90° Close	9.0	2.2	6.5	7.9	9.1	10.2	11.6
2 Hand Lying Side Lift Legs Braced Close	9.2	1.9	6.6	7.9	9.2	10.4	11.4
2 Hand Lying Side Lift Legs @ 90° Far	9.7	2.2	7.4	8.2	9.5	11.1	12.2
2 Hand Lying Side Lift Legs Braced Far	9.6	2.0	7.3	8.2	9.4	11.3	12.2

Table 12. MMH Capacity Data (kg) for Male Subjects in Experiment 3c.

MMH Activity	Mean	SD	Percentile Distribution of Data 10	25	50	75	90
1 Hand Lying Side Lift Legs @ 90° Close	14.7	2.7	11.6	12.9	14.8	15.6	18.1
1 Hand Lying Side Lift Legs Braced Close	14.9	2.6	11.9	12.7	14.7	17.0	17.8
1 Hand Lying Side Lift Legs @ 90° Far	14.6	2.4	11.4	12.7	14.7	16.1	17.4
1 Hand Lying Side Lift Legs Braced Far	14.5	2.7	11.0	12.5	14.6	16.3	18.4
2 Hand Lying Side Lift Legs @ 90° Close	17.9	3.2	13.5	15.9	17.7	20.4	21.4
2 Hand Lying Side Lift Legs Braced Close	18.0	3.9	12.8	15.0	17.8	20.6	23.2
2 Hand Lying Side Lift Legs @ 90° Far	19.0	2.9	15.8	17.2	18.6	21.1	22.5
2 Hand Lying Side Lift Legs Braced Far	19.1	3.6	14.8	16.8	18.6	22.0	23.6

Experiment 4.

Experiment 4 examined manual materials handling tasks that involved the lifting and carrying of boxes in environments with restricted ceiling heights.. Forty Texas Tech students (20 males and 20 females) were recruited to participate in the study and all 40 subjects completed the experiment. The subjects were selected to be representative of the U.S. adult population and were selected according to the height-weight criteria of Tables 1 and 2. The subjects used in Experiment 4 were not the same subjects used in previous experiments.

A 61 x 30 x 15cm container without handles was used for the carrying tasks at unrestricted ceiling height, 80% of stature ceiling and 60% of stature ceiling heights. A container of the same size, but with handles was used for the restricted ceiling at 40% of stature for the two handed lift and carry activity. Two containers were used, one with an empty mass of 13.6kg and the other with an empty mass of 36.3kg. Weight adjustment was accomplished by adding or subtracting unmarked rods that weighted 2.25kg each. Incremental weights were inserted into pipes in the boxes, which prevented the weight from shifting while the subject lifted and carried the load.

For the one-hand carry at 40% of stature height, male subjects used a box measuring 38 x 27 x 27cm, while the females used a slightly smaller container measuring 38 x 20 x 20cm. Both containers resembled toolboxes with a pipe handle running the 38cm length of the container. Weight adjustment for the one-hand box was also in 2.25kg increments.

The subjects were allowed to utilize a freestyle method of handling the boxes, but were restricted to forward movement and duckwalking was prohibited. Subjects were not allowed to slide or drag the box across the floor. After a successful trial, the subject was asked if he or she could safely handle more weight and wanted to repeat the trial. The experimenters terminated a trial if the subject appeared to be having trouble handling the load, or if the subject was staggering or dropping the load instead of gently lowering it to the floor. A minimum of ten minutes was allowed between each task.

A psychophysical methodology was again utilized in Experiment 4 to determine the subject's one time maximum acceptable weight of lift and carry for the various task conditions. The subject was under no time constraints and could make as many adjustments as necessary to arrive at his or her maximum acceptable weight of lift for a one time lift and carry for a distance of 3m. The box was weighed after the subject left the test area, and no performance feedback was provided to the

subject. The order in which the tasks were completed was randomly determined for each subject. The experiment was conducted in two hour sessions, with no subject being permitted to attend more than one session per day.

The tasks studied in Experiment 4 included:

1. **Lift and Carry 3m Unrestricted Ceiling Height-** The subject bent down and lifted the box with both hands from the floor to knuckle height, carried the box in front of the body for 3m using normal upright carrying posture, then lowered the box back onto the floor.

2. **Lift and Carry 3m Ceiling 80% of Stature-** The subject bent down and lifted the box with both hands from the floor, carried the box in front of the body for 3m using a slightly flexed neck and trunk posture, then lowered the box back onto the floor.

3. **Lift and Carry 3m Ceiling 60% of Stature-** The subject bent down and lifted the box with both hands from the floor, carried the box in front of the body for 3m using a flexed neck and very flexed trunk and knees posture, then lowered the box back onto the floor. The method of carry was determined by the subject, although two forms of carrying emerged: the load was either held near chest/resting on thighs, or else the load held in front of knees while being carried.

4. **Lift, Carry (2 Hand), Crawl 3m Ceiling 40% of Stature-** The subject was positioned on his or her hands and knees under the restricted ceiling, with the box placed in front of body. The carry activity was not a continuous activity. The subject grasped the handle of the container with both hands, lifted the box and repositioned the box at arms length in front of him or her. Then the subject crawled to the container and repeated the sequence until he or she had traveled the 3m distance. Both of the subject's hands remained in contact with box handle throughout the carry activity.

5. **Lift, Carry (1 Hand), Crawl 3m Ceiling 40% of Stature-** The subject was positioned on his or her hands and knees under the restricted ceiling, with the box placed on the preferred side of the subject's body. The carry activity was not a continuous activity.The container was lifted off the floor, carried forward, and lowered with preferred hand (while other hand supported the subject's body). The subject repeated the crawling sequence until the 3m distance had been covered. The subject's preferred hand remained in contact with box handle throughout the carry activity.

The capacity data and population percentiles for Experiment 4 are presented in Tables 13 and 14. Table 13 shows the capacity data for female subjects, while Table 14 shows the capacity data for the male subjects. The capacity data obtained from Experiment 4 was in increments of 2.25kg, and many of the subject's capacities were the same. This can be seen in Tables 13 and 14 when two adjacent percentiles are the same value.

Table 13. MMH Capacity Data (kg) for Female Subjects in Experiment 4.

MMH Activity	Mean	SD	Percentile Distribution of Data 10	25	50	75	90
Lift and Carry 3 m Unrestricted Ceiling Ht	35.8	6.4	27.2	31.8	36.3	39.7	45.4
Lift and Carry 3 m Ceiling 80% of Stature	33.2	5.1	27.2	29.5	34.0	35.2	39.7
Lift and Carry 3 m Ceiling 60% of Stature	24.5	5.7	18.1	20.4	23.8	27.2	34.0
Lift, Carry (2 Hand), Crawl 3 m Ceiling 40% of Stature	19.3	2.9	15.9	17.0	20.4	20.4	22.7
Lift, Carry (1 Hand), Crawl 3 m Ceiling 40% of Stature	18.8	3.3	14.8	17.0	18.1	22.7	22.7

Table 14. MMH Capacity Data (kg) for Male Subjects in Experiment 4.

MMH Activity	Mean	SD	Percentile Distribution of Data 10	25	50	75	90
Lift and Carry 3 m Unrestricted Ceiling Ht	68.8	13.3	51.0	59.0	69.2	73.7	90.8
Lift and Carry 3 m Ceiling 80% of Stature	66.6	11.7	49.9	59.0	65.8	72.6	80.5
Lift and Carry 3 m Ceiling 60% of Stature	50.8	12.0	37.4	42.0	48.8	57.8	69.2
Lift, Carry (2 Hand), Crawl 3 m Ceiling 40% of Stature	29.1	4.0	24.9	27.2	28.4	31.8	35.2
Lift, Carry (1 Hand), Crawl 3 m Ceiling 40% of Stature	30.7	4.4	26.6	28.1	30.4	32.7	36.0

4. Conclusions

This paper has presented capacity data for manual materials handling in non-standard postures. Such data should be useful to the ergonomist in job analysis and design for those manual materials handling tasks that are not two-handed, symmetric, sagittal plane lifting. The data are not expected to cover all non-standard situations, but should be useful in providing insight into population capacities for the evaluation and design of similar activities. Except for Experiment 1, in which a frequency of 6 lifts/minute was utilized, all other data represent capacities for a one-time occurrence. The one-time capacity data would not be appropriate to use for repetitive tasks.

5. References

Ayoub, M. M., and Halcomb, C. G., 1976, *Improved Seat Console and Workplace Design*, Technical Publication TP-76-7, U. S. Navy, Pacific Missle Test Center.

Ayoub, M. M., Smith, J. L., Selan, J. L., and Fernandez, J. E., 1985a, *Manual Materials Handling in Unusual Positions- Phase I*, Final Report prepared for the University of Dayton Research Institute.

Ayoub, M. M., Smith, J. L., Selan, J. L., Chen, H. C., Fernandez, J. E., Lee, Y. H. and Kim, H. K., 1985b, *Manual Materials Handling in Unusual Positions- Phase II*, Final Report prepared for the University of Dayton Research Institute.

Ayoub, M. M., Smith, J. L., Selan, J. L., Chen, H. C., Lee, Y. H. and Kim, H. K., 1987, *Manual Materials Handling in Unusual Positions- Phase III*, Final Report prepared for the University of Dayton Research Institute.

Ayoub, M. M., Smith, J. L., Chen, H. C., Danz, M. E., Kim, H. K., Lee, Y. H., and Ostrom, L. T., 1988, *Manual Materials Handling in Unusual Positions- Phase IV*, Final Report prepared for the University of Dayton Research Institute.

NIOSH, 1981, *Work Practices Guide for Manual Lifting*, DHHS Publication No. 81-122.